Trends and Motivation

Internet emerged as the global platform for communication
- Sustained traffic growth due to fixed/mobile broadband access
  ➔ Migration towards optical metro and core networks
- Highly dynamic and asymmetric traffic profiles
  ➔ Flexible packet transport
- Next generation networks demand quality of service QoS
  ➔ Support from transport networks

OBS proposed as long-term IP-over-WDM solution
- Scientific work centers around QoS of OBS-only scenarios
- Few realization and scalability evaluations
  ➔ How to find optimal architectures combining QoS and realization arguments?
- Missing evolution link to existing wavelength-switched networks
  ➔ How to build burst-switched networks on wavelength-switched networks?

Outline

- Optical burst switching architecture
  - Introduction and functional components
  - Contention resolution for high QoS
  - Integrated evaluation including realization and scalability
- OBS meets wavelength-switching
  - Motivations for virtual topology
  - Key trade-offs and realizations
- Optical Burst Transport Network (OBTN)
  - Network and node architecture
  - Performance evaluation

Optical Burst Switching

- Burst assembly in edge node:
  - IP packets ➔ optical bursts
  - One-way signaling
- Separation of control and data

Optical Burst Switching

- Burst assembly in edge node:
  - IP packets ➔ optical bursts
  - One-way signaling
- Separation of control and data
  - Fast optical burst switch with fiber delay line buffer (FDL)
Contest resolution reaction in case of burst scheduling conflict

- Increasing the number of wavelengths improves QoS

FDL Buffer Performance

- Wavelength domain – wavelength conversion
  - very effective as all WDM channels shared among all bursts
  - but: low burst loss probabilities only for $\geq 100\lambda$s
  - additional schemes necessary

- Time domain – buffering
  - simple fiber delay lines (FDLs) in nodes
  - no random access functionality
  - FDL operated in WDM
  - prioritized reservation of buffered bursts with JET possible

- Space domain – deflection/alternative routing
  - uses entire network as resource for contention resolution
  - additional network load due to detours $\Rightarrow$ positive feedback

OBS Node with FDL buffer

- Recirculation buffer
  - Shared per node
  - Coordinated scheduling

- Degenerate buffer $T = FD L = 1, ..., F$

- Degenerate Buffer
  - FDLs in buffer $F$
  - wavelengths per FDL $w$
  - total number of ports $P = F \cdot w$
  - delay granularity $D$

FDL Buffer Performance

- Different buffer configurations with same $P$ yield comparable performance
  - select the configuration based on realization arguments
Integrated Evaluation

- Many ports: QoS depends on buffer configuration
  - select the configuration based on realization arguments
- Further evaluate QoS and realization trade-off

• Power loss
• Noise of SOA and EDFAs

Architecture Modelling Analysis Interpretation

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Node Parameters

Impact on performance
- Number of fibers \(N\)
- Number of wavelengths per fiber \(M\)
- Contention resolution scheme

Impact on signal
- Splitting loss: \(1/N\) per fiber
- Noise of SOA and EDFAs
- Crosstalk
- Power loss

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TAS with FDL Buffers

→ Performance Improvement
- due to buffering
  - TAS-shFDL: multiple FDLs

→ Signal Degradation
- due to increased splitting loss
- due to loss in FDL

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Evaluation Methodology

1. Analysis of signal degradation between two regeneration points
   - TAS-shFDL: node-to-node path is critical signal path
   ⇒ maximum number of wavelengths per fiber $M_{\text{max}}$
   ⇒ maximum throughput

2. Simulation of OBS node using $M_{\text{max}}$
   ⇒ utilization for a given tolerable burst loss probability $P_{\text{loss}}$
   ⇒ effective throughput

Maximum Throughput

- Maximum throughput always between 2 and 6 Tbps
- Greatest for TAS and smallest for TAS-dFDL
- More FDLs in TAS-shFDL yield smaller nodes

Effective Throughput

- Effective throughput between 1.5 and 4 Tbps
- FDL buffers improve utilization
- More FDLs lead to better utilization but also to smaller nodes
  ⇒ some TAS-shFDL yield lower effective throughput than TAS

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Wavelength Switching

- Transports packets in lightpaths
- Two-way signaling based on ASON, GMPLS, "lambda grid"
OBS meets Wavelength Switching

- Optical burst switching (OBS)
  - Fine-grain statistical multiplexing
- Wavelength switching
  - Coarse-grain provisioning and recovery
  - Mature technology → inexpensive bandwidth
- OBS is often proposed to replace wavelength-switched core networks
  - But: lambda grids are well-suited for core transport networks
  - But: high aggregation does not require fine-granular statistical multiplexing

Motivations for Virtual Topology

- First introduction of burst techniques more likely in MANs
  - Efficient burst transport across core network
  - Cost of switching dominates cost of transport
  - Reduction of node size becomes a primary concern
  - Bypass intermediate nodes to reduce transit traffic

Virtual Topology Trade-offs

- Sparsely meshed
  - e.g. virtual = physical topology
  - high stat. mux gain
  - high link utilization
  - high transit traffic
  - OBS
Virtual Topology Trade-offs

**Sparsely meshed**
- e.g. virtual = physical topology
- high stat. mux gain
- high link utilization
- OBS

**Densely meshed**
- e.g. virtual = full mesh
- low stat.mux gain
- low link utilization
- Burst-over-Circuit Switching (BoCS)

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Optical Burst Transport Network (OBTN)

- Traffic demands
- Physical topology
- OBS virtual topology

1. Direct lightpaths as virtual links
   - Minimizes transit traffic
Optical Burst Transport Network (OBTN)

1. **Direct lightpaths as virtual links**
2. **Constrained alternate routing** along fiber links of primary route
   - Resolves contention without route length variation

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Optical Burst Transport Network (OBTN)

1. **Lightpaths as multi-hop virtual links**
2. **Constrained alternate routing** along fiber links of primary route
3. **Shared overflow capacity** compensates for traffic on alternate routes
   - Improves statistical multiplexing as aggregated on few single-hop virtual links

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Optical Burst Transport Network (OBTN)

1. **Lightpaths as multi-hop virtual links**
2. **Constrained alternate routing** along fiber links of primary route
3. **Shared overflow capacity** compensates for traffic on alternate routes
4. **Effective contention resolution**
   - Achieves high QoS and utilization

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OBTN Node View

- **OBTN node realized like OBS node (e.g. TAS, BAS, AWG, ...)**

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Unified Modeling of Architectures

- **Resource metrics**
  - Number of ports in burst-switched nodes
  - Number of fiber hops in physical network

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Performance Evaluation

- **European reference topology as core network**
  - 16 nodes
  - 23 links in physical topology
- **Optical MANs abstracted as traffic sources**
- **Traffic**
  - Population-based demand model, approx. 10 Tbps
  - Poisson arrivals
  - Exponential burst transmission time, mean $h = 10\mu s$
- **FDL buffer**
  - Single FDL using WDM with 32 wavelengths
  - Delay of 4 mean burst transmission times
QoS Comparison

- BoCS requires much higher overprovisioning than OBS
- OBS in between BoCS and OBS
  - \( \beta \): shared overflow capacity allocation is very effective

Number of Switch Ports

- OBTN requires fewest number of ports – trunk and overall
- Small \( \beta \) already effective \( \rightarrow \) few shared overflow capacity

Node and Network Resources

- OBTN requires fewest number of ports – trunk and overall
  - Small \( \beta \) already effective \( \rightarrow \) few shared overflow capacity
Node and Network Resources

OBTN achieves
- Reduced number of burst-switched ports regarding OBS and BoCS
- Penalty in number of wavelength hops compared to regular OBS

Overall cost reduction honoring cost structure

Alternative OBTN Virtual Topologies

Alternative virtual topology design
- Path length-based
- Demand-based
- Combined

Less densely-meshed virtual topologies in OBTN feasible
- slightly less fiber hops
- slightly more switch ports

Conclusions

- FDL buffers effectively resolve contention
  → Low burst loss probability at high channel utilization
- Additional ports to be considered in integrated evaluation of scalability
  → Buffer has significant impact regarding signal degradation
  → Few or no improvement regarding the maximum effective throughput

- Motivations and key trade-offs for burst transport with virtual topology
- Optical Burst Transport Network (OBTN) architecture introduced
- Unified resource modeling of OBS, BoCS, and OBTN

Performance and resource evaluation for OBTN
- Yields overall high quality of service
- Reduces switch ports with limited penalty in network capacity compared to OBS
  → Overall reduction of resource requirements

Outlook

Integrated performance and technology analysis
- Broader application in projects
- Provide simplified models for non-experts

Further OBTN modeling and evaluation
- Optimal virtual topology design
- Extend resource studies to technological scalability analyses
- Control plane issues
- Migration scenarios for OBS: performance, technology, control, business...

Research on photonic networks and systems: We should...
- ... narrow the gap between technology, systems, networks, and applications
- ... also build the stuff, lots of activities in Asia
- ... watch the research networks community

Architectures for Optical Burst Transport Networks
- A View Beyond QoS -

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